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Q. J. Stober and A. H. Hamalainen

FINAL REPORT

January 1, 1979 to September 30, 1979

Washington State Department of Fisheries
Olympia, Washington

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FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
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Robert L. Burgner, Director
Fisheries Research Institute

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1.0 ABSTRACT

The estimated escapement of 277,801 sockeye salmon in 1978 was the fourth largest recorded in the Cedar River. Sockeye eggs were not subjected to discharges greater than $47.6 \text{ m}^3/\text{s}$ during the 1978-79 incubation period. The emigration of fry in 1979 was estimated at 25.5×10^6 ($\pm 2.6 \times 10^6$), which included the unknown survival from 9.5×10^6 fry artificially produced in the WDF incubation facility at Landsburg. The egg-to-fry survival for the entire run was 4.5 percent. The lowest survival (3.9%) occurred during the early emigration when 87 percent of the artificial fry emerged. Infectious hematopoietic necrosis (IHN) was suspected to have reduced the survival of artificially-produced fry in 1979.

Brood years 1975, 1976 and 1978 were compared with associated environmental conditions. A severe reduction in the natural spawning habitat followed an extreme flood in 1975 and was sustained through the 1977 brood year. It is probable that no substantial increase in spawning habitat occurred in 1978. Environmental conditions experienced by brood years 1976 and 1978 were comparable, flood effects were minimal both years. Escapement doubled the second year, with an estimated increase in production of 2.7×10^6 fry. Egg-to-fry survival declined from 8.1 percent in 1976 to 4.5 percent in 1978. The estimated presmolt-to-spawner ratio was 20.1 and 7.7 for the 1976 and 1978 brood years, respectively. The percent of complete fusion also declined from 90.1 in 1976 to 55.8 in 1978. Density dependent mortality due to redd superimposition and disease were the most likely causes of the low survival.

2.0 ACKNOWLEDGMENTS

This investigation was supported by funds provided by the Washington State Department of Fisheries (WDF). Cooperation from the WDF, U.S. Geological Survey (USGS), City of Seattle Water Department and the Renton Municipal Airport is greatly appreciated.

We express our appreciation to the following Fisheries Research Institute (FRI) personnel who provided valuable field assistance throughout the study: Rick C. Krueger, Craig Olds and R. Robert Zisette.

3.0 INTRODUCTION

Anadromous sockeye salmon from Baker Lake, Washington, were first introduced into the Lake Washington watershed in 1935 (Woodey 1966). Adult returns were insignificant from brood years prior to 1960 (Kolb 1971). Since 1964 the escapement levels to the Cedar River have exceeded 100,000 sockeye, with the maximum of 410,000 adults in 1977. The run now is of economic and biological importance to the State and the Seattle metropolitan area and is presently the largest United States run of this species outside of Alaska.

Woodey (1966, 1972) described the life cycle of the Lake Washington sockeye. The adults return to the lake from June to August and remain in the lake for 1-4 months before spawning. Usually over 90 percent of the escapement spawns in the Cedar River from late August through late December. The fry emerge from the gravel and migrate down the river from January through late May, and shortly after entering the lake, move offshore into the limnetic zone. The primary growing period is from June through October. Zooplankton forms the principal food source. After 12-15 months rearing in the limnetic zone, the juveniles smolt and migrate to sea during the spring.

Instream flow requirements for sockeye spawning, incubation and emergence have received considerable attention because the Cedar River is the primary source of municipal and industrial water supply for the Seattle metropolitan area. The effects of river discharge on spawning area utilization were determined by Collings et al. (1972) and Stober and Graybill (1974). Miller (1976) investigated the relationships between discharge, fish production, and water supply, while the biological production of Lake Washington sockeye was modeled by Bryant (1976). The effects of a major flood, instream spawning flows and

density-dependent mortality factors on sockeye fry production were determined by Stober et al. (1978a). Monitoring during the 1977 spawning season was also conducted in order to obtain data on the largest escapement in the Cedar River (Stober et al. 1978b). The resulting fry production, however, was not determined in 1978.

This report presents and interprets the data on (1) the environmental conditions during the 1978-1979 season; (2) escapement; and (3) artificial enhancement and natural sockeye fry production in 1979. Interpretations of the present data have been made by comparison to previous results in order to yield information useful in the future management of this run.

4.0 DESCRIPTION OF STUDY AREA

The Cedar River drainage area covers 487 km². The river heads on the west slope of the Cascade Mountains, flows across the lowlands of the Puget Sound area, and empties into the southern end of Lake Washington (Fig. 1). Average annual rainfall ranges from 250 cm (primarily as snow) to 80 cm near the mouth (generally as rain). Hydrographic analysis of river discharge indicated high flows during winter and low flows during late summer, a pattern typical of lowland streams. Melting snow in the watershed during the spring may increase the runoff.

The discharge of the Cedar River is regulated both by operation of the Cedar Falls hydroelectric station below Chester Morse Lake and by an annual diversion of about 4.8 m³/s at Landsburg by the Seattle Water Department. Only 34.8 km of the river are available to anadromous salmonids such as sockeye, chinook and coho salmon, and steelhead and cutthroat trout due to the Landsburg diversion dam.

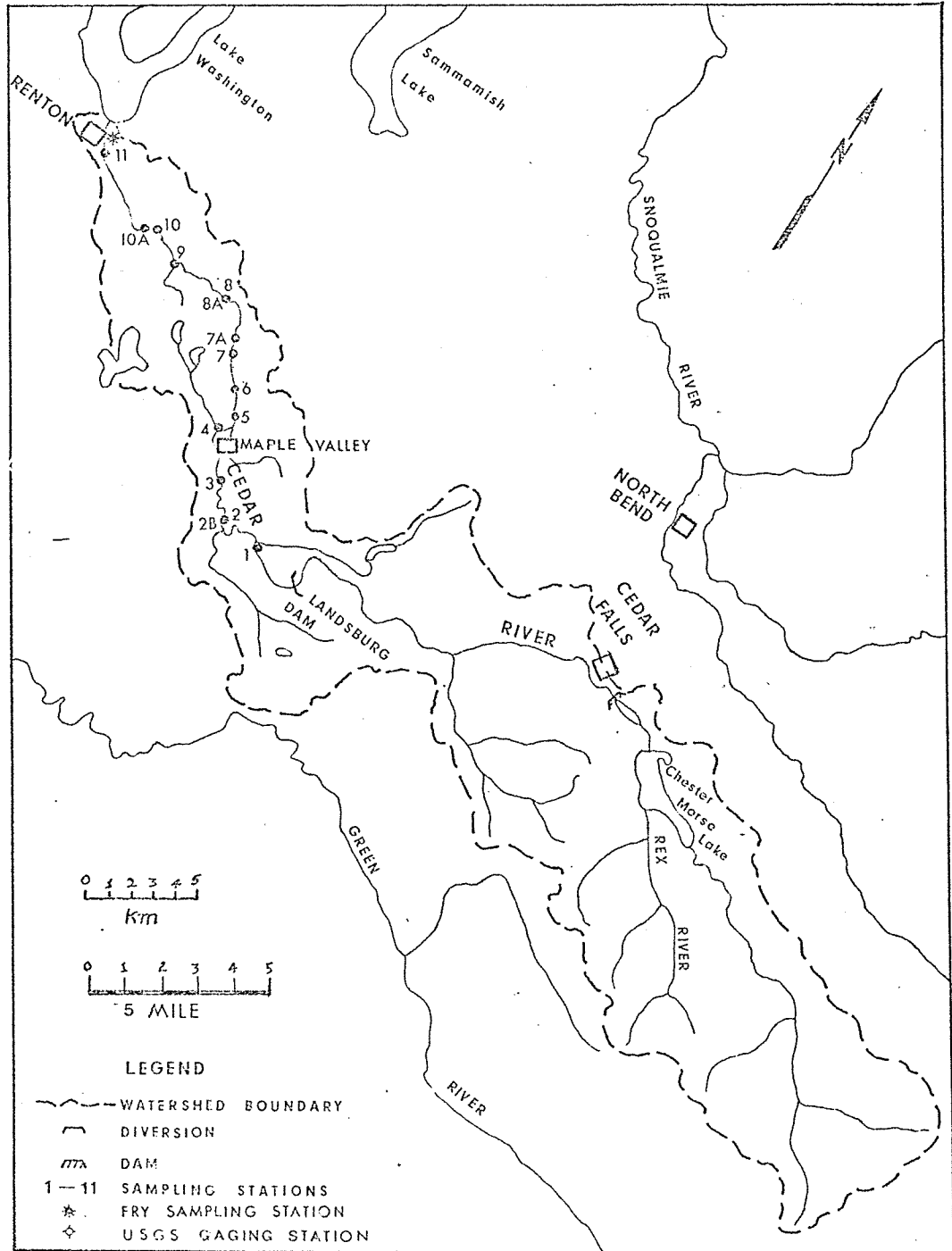


Fig. 1. Map of Cedar River watershed, showing location of study reaches, stream gauges, and fry sampling station.

Fry sampling was conducted near the mouth of the river at the exact location of the 1976 and 1977 studies (Fig. 1). The site was selected because it lies below all spawning areas in the river and was restricted to the general public. Electric power was obtained from Renton Municipal Airport. The channel at this site was straight with a coarse gravel bottom substrate. A cross-sectional contour (Fig. 2) indicated a bar along the east side of the channel and maximum depth along the west bank. The river width was 40.3 m. The average depth varied from 0.4 m to 0.8 m. Midchannel current velocities ranged from 0.4 to 1.2 m/s. In general, the discharge pattern decreased from February through May.

5.0 MATERIALS AND METHODS

5.1 Potential Egg Deposition and Timing of Emergence

Estimates of the potential egg deposition were based on the following assumptions: (1) the female-to-male ratio was 58:42, and (2) the average egg deposition of each female was 3,500 eggs. Purse seine test fishing (Jewell et al. 1969) and the 1976 WDF sockeye enhancement program near the river mouth found a 58:42 female-to-male ratio. The average Cedar River sockeye fecundity was determined by Heiser (1962) and Bryant (1976) to be about 3,500 eggs.

The expected timing of emergence was calculated for weekly spawning populations based on the 1978 tower counts and previous incubation studies (Stober et al. 1978a). The number of temperature units calculated varied with the average incubation temperature. We assumed that fish deposited their eggs in an average of seven days after passing the counting tower. This time period probably was longer than seven days in the beginning, and shorter at the end of the spawning

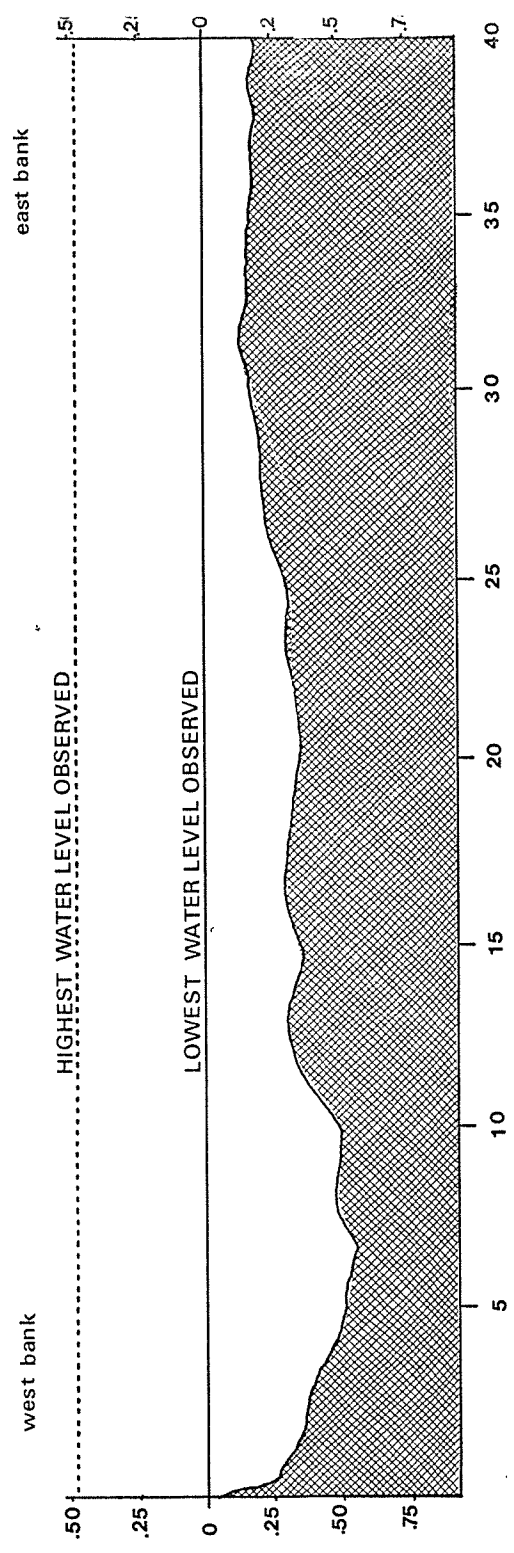


Fig. 2. Cross-section of the Cedar River at the fyke net sampling site.

season. The sockeye which were in the river prior to tower counting were assumed to delay their spawning and were allocated to the first four weekly tower counts on the basis of 10, 20, 30 and 40 percent, respectively. Since dissolved oxygen concentration in the water immediately surrounding the eggs may have affected the rate of development, 56 temperature units (C) (TU, defined as 1°C above 0°C for a 24-hour period = $5/9 \times \text{TU F}$) were added to correct for potential oxygen deficits (Brannon, personal communication).

5.2 Emigrant Fry Sampling

The fyke net apparatus described in the 1976 and 1977 studies was used again to sample the emigrant sockeye fry (Stober et al. 1978a). This apparatus, powered by an electric winch, was easily operated by one person.

The net measured 1.5 x 1.5 m at the mouth, tapering uniformly within 7.0 m to a 0.2-m diameter opening, where a vinyl collar provided a reinforced surface for clamping to a live tank (Fig. 3). The net was made of 3-mm knotless nylon mesh. The seams were sewn with nylon tape and reinforced with polypropylene lines, which attached the net to the frame. A vinyl collar encircled the net mouth to provide a strong, abrasion-resistant surface. The cleaning of the cod end was facilitated by a zippered opening.

The net frame was constructed of 13-mm steel rod and galvanized pipe (Fig. 3). A variable-pitch depressor plate was bolted to the frame to stabilize the net, while two rubber collars held it slightly off the bottom.

Fish were funneled into a submersible live tank (Fig. 3). The two end cones were made from 3-mm black iron sheet metal and connected with angle iron. The cylindrical tank measured 1.9 m in length and 0.7 m in diameter. Two steel rings were welded to the tank frame. Two floats and seven plywood panels were

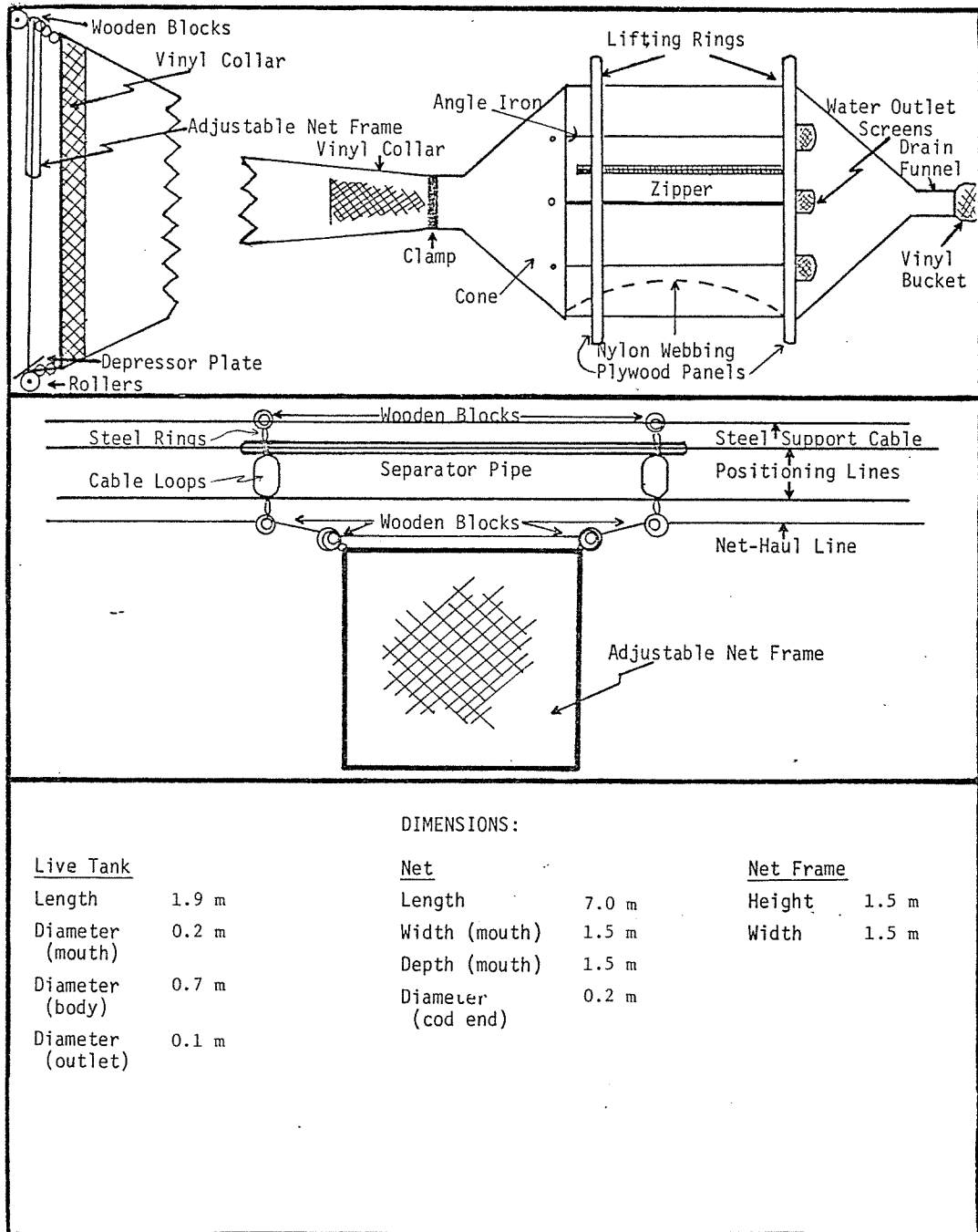


Fig. 3. Schematic diagram of the sockeye fry sampling nets, live tank, and positioning gear.

attached to the lifting rings to protect the net from bottom abrasion. A 3-mm knotless nylon webbing net was suspended inside the live tank frame. A full-length zipper facilitated removal of debris.

The fyke net was suspended from a 14-mm steel cable placed across the river and supported by two A-frames. These were constructed of 10 x 10 cm wood beams and anchored to two railroad ties buried in the ground (Figs. 4 and 5). Tension on the cable was adjusted by a large turnbuckle.

Movement of the net was facilitated by a polypropylene rope (positioning line) running through wooden blocks hung from the A-frame to a hand winch. A galvanized separator pipe with rings at each end was attached to the positioning line. Two wooden blocks, which travelled on the support cable, were secured to the pipe rings by cable loops. Hung below these rings were two blocks to which the lower corners of the net frame were secured by ropes. The 13-mm net haul line ran through these, and two similarly-sized blocks in the top of the net frame and then through a steel snatch block secured to the A-frame. The net haul line was attached by a 45.8-m cable to a 3,632-kg capacity electric winch used to lift the net out of the water.

The net was set by moving it with a hand winch above the water to the desired location indicated by tape marks along the positioning line. The net haul line was then disengaged and the river current pulled the net into fishing position. This procedure was reversed for retrieval.

The live tank was lifted with a small hand winch from the river to remove the catch. The lifting apparatus consisted of a long boom, supported by a small A-frame mounted on a platform on the river bank. Fish and debris were released through the drain funnel into a plastic bucket, and fish were identified, counted and returned to the river unharmed. Weekly subsamples were taken for length, weight, and condition determination.

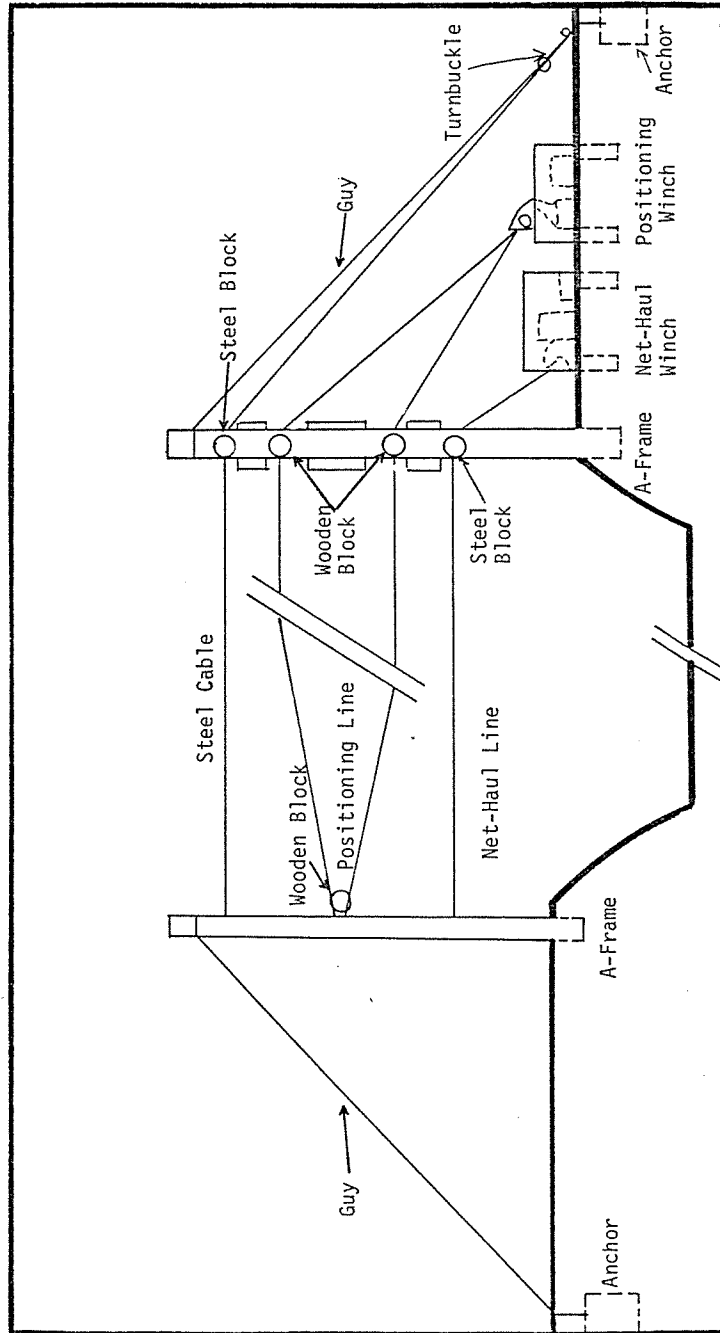


Fig. 4. Schematic diagram of the fyke net apparatus (side view).

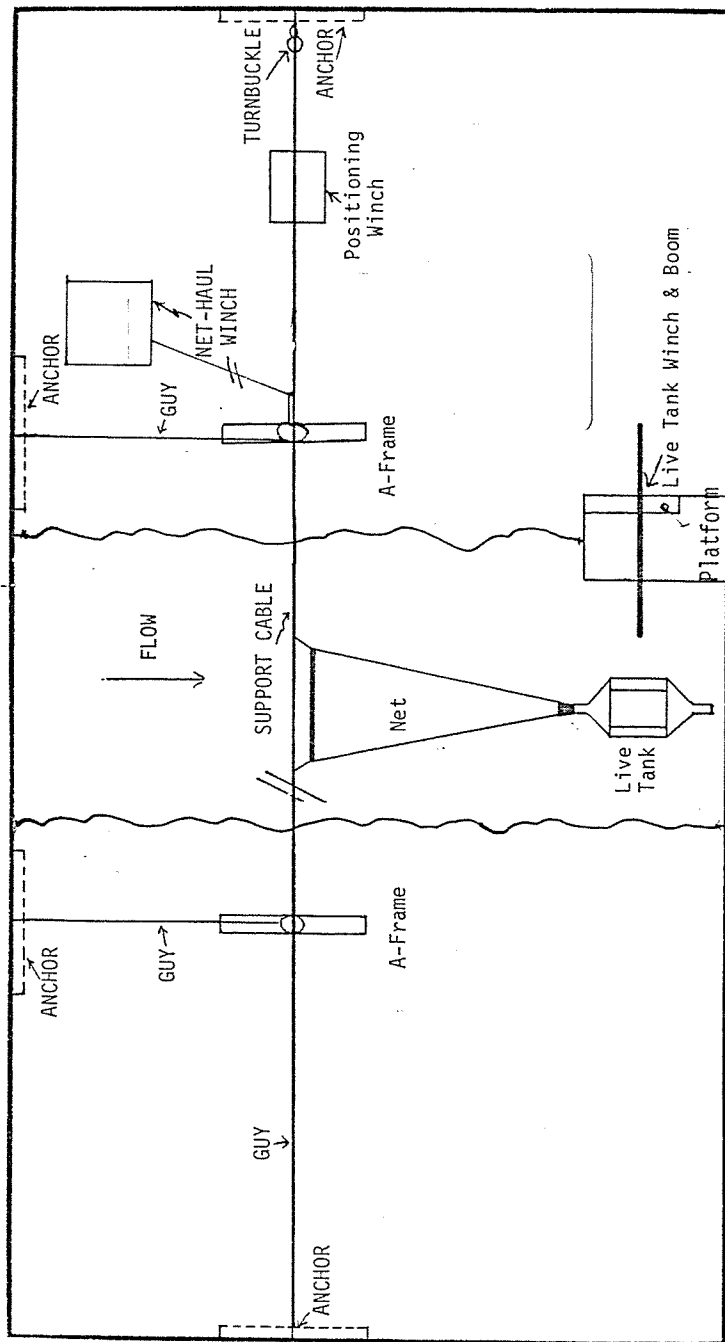


Fig. 5. Plan view of the sockeye fry sampling apparatus.

Sampling mortality caused by netting and handling was determined on a small number of fry (usually 100-160) which were periodically placed in a large, darkened, plastic garbage can with aerated water. After 10-13 hours, the number of dead or fatally injured fry was recorded. No attempt was made to separate various causes of mortality.

The catch efficiency of a net may be considered to be 100 percent if it catches and holds all the fry it intercepts. Since no reduction in water velocity inside the net mouth was observed and the velocities remained above 30.0 cm/s, the catch efficiency was assumed to be 100 percent. Bams (1967) reported that the critical swimming speeds for sockeye fry were of the order of six to seven body lengths per second (17.5 cm/s). Andrews and Geen (1960) stated, "...in any river where sockeye fry are required to migrate upstream to their rearing lake, continuous marginal paths in which the velocity does not exceed 0.5 fps (15.2 cm/sec) for a distance of 1.5 ft (46 cm) should be available." Greenland and Thomas (1972) found that chinook fry, which were larger than sockeye fry, could not maintain their position in current with velocities above 17.5-20.0 cm/s. These studies supported our assumption of negligible net avoidance.

5.2.1 Sampling Design

Diurnal sampling conducted in 1976 and 1977 showed insignificant emigration during daylight hours (Stober et al. 1978a). Therefore, nightly sampling was begun prior to sunset and ended after sunrise. The same four sampling locations as in 1976 and 1977 were chosen at distances of 4.6, 10.0, 16.5 and 22.0 m from the left bank. A random sampling scheme among these four sites was used to derive an estimate of the total fry emigration. Each net set was limited to 1

hour at each site to minimize both debris accumulation and the holding time of fish, and to allow a greater chance to sample all sites each night. One-half hour was allowed between each set to process the catch and to clean and reset the net.

Pertinent fyke net sampling data were recorded on Fisheries Research Institute (FRI) coding form S.170.3 (Cedar River Research Fyke Net Data Form). Air and water temperatures were measured hourly with a pocket thermometer during the sampling operation. The river height was determined from a staff gauge installed at the site. Information on cloud cover, light, and precipitation was also recorded. Daily turbidity determinations were made with a Hach kit. Periodic depth and velocity readings were made using a Marsh-McBirney electronic current meter.

Samples were taken once or twice a week between January 26 and March 4, and May 20 and June 7. Sampling was conducted during the main emigration period three times weekly (usually Monday, Tuesday and Thursday).

5.2.2 Fry Estimation

Weighting factors based on the horizontal distribution of fry across the river channel were used to expand the hourly catches into estimates of the entire fry population passing the sampling station. The relative proportions of the mean hourly catches taken at each site during each of the three seasonal periods were computed. These points were graphed according to their location across the river channel and connected linearly with both banks. The percentage of the sampled area (1.5 m wide at each site) of the total area under the curve was computed and the reciprocal was utilized as the weighting factor for that site and seasonal time segment. Fry estimates in 1976 and 1977 were obtained by multiplying the hourly catches by these weighting factors.

Estimates of the daily emigration were derived by using the formula:

$$N_i = (\beta_i) \sum (k_{s,t} \times C_{j,s,t}), \quad (1)$$

where

- N_i = estimated number of fish emigrating on day i ,
- β_i = $\frac{\text{hours from the beginning to the end of sampling}}{\text{actual hours fished}}$,
- $C_{j,s,t}$ = number of fish caught during set j , site s , and period t ,
- $k_{s,t}$ = weighting factor for site s and period t .

Weekly emigration rates were computed by the expression:

$$T_k = \frac{n_k \sum N_i}{m_k}, \quad (2)$$

where

- T_k = estimated weekly emigration rate,
- n_k = number of days in week,
- m_k = number of days sampled per week (1 to 3).

The point estimate for the season was calculated from:

$$T_c = \sum T_k, \quad (3)$$

where

T_c = total estimate for the season.

True variance for the net catches could not be determined because only one net was employed throughout the study. Variance for the entire season was approximated as follows: hourly estimates, excluding the first and last set of the night (these were always small due to partial daylight), were multiplied by the number of hours of daily emigration and treated as population estimates to compute daily variances. These were summed up over the entire season to construct the confidence interval for the estimate. The main components of the daily variance, however, were the large diel and site variations, resulting in larger than the true variance. Assuming that $C_{j,s,t}$ are independent random variables, $\text{Var}(\hat{T}_c)$ was estimated from:

$$\text{Var}(\hat{T}_c) = \sum \frac{n_k}{m_k} \sum \text{Var}(Ni) . \quad (4)$$

The interval estimate was then obtained from:

$$T_c \pm Z_\alpha \sqrt{\text{Var}(\hat{T}_c)} \quad (5)$$

where

Z_α = 95 percent normal probability, critical value = 1.96.

5.2.3 Fry Quality

Length-weight data were collected from fry samples to provide indication of growth and to detect changes in size, condition, and stage of development. A weekly subsample of about 100 sockeye fry was preserved in 10 percent formalin and brought to the laboratory. At least 10 days were allowed for length and weight to stabilize (Rogers 1964). The fork lengths of 50 fry were measured to the nearest millimeter. Fry were blotted to remove excess moisture and weighed individually to the nearest hundredth of a gram on a balance. The lengths and weights were recorded on Form S130.2 (IBP Fish Length and Weight Data Form) and were analyzed using FRI computer program FRD294 (Length Frequency Analysis). Student Neuman-Keuls test ($\alpha = 0.05$) was used to establish significant within-season changes in length and in weight, while a t-test was performed to detect differences between years. Condition factors were computed using the formula:

$$\text{Condition factor} = \frac{(\text{mean weight in grams}) \times 100}{(\text{mean length in centimeters})^3} \quad (6)$$

The stage of development was classified: 1) complete fusion of the midventral wall; or 2) some yolk visible externally.

6.0 RESULTS AND DISCUSSION

6.1 Water Quantity and Quality

A hydrograph of the river discharge recorded at the USGS gauging station at Renton is presented for the period from August 1978 through June 1979 (Fig. 6). Mean daily discharges increased gradually during the fall spawning season and ranged from 2.5 m³/s in late August to 21.5 m³/s on November 4. The discharge regime generally followed the DOE operating curve during the spawning season. A peak discharge of 21.5 m³/s was observed on September 23. The discharge increased again in November to a maximum of 47.6 m³/s on December 1, followed by a general decline and peaking again at about 47.0 m³/s on February 12 and March 7. The discharge generally declined throughout the remainder of the incubation period. Maximum instantaneous discharges less than 50 m³/s have been shown to have little effect on sockeye survival by comparison to the pre-smolt to spawner ratio (Stober et al. 1978).

During the 1978 spawning season, the discharge pattern exceeded the DOE operating curve as well as the lower discharge regime suggested by Stober and Graybill (1974), and may have contributed to an increase in redd superimposition; however, no observations to determine this were made. The maximum flow (47.6 m³/s) occurred late in the spawning season and was only slightly higher than 34.6 m³/s observed in the 1976-1977 season. The flow regimes during both years presented ideal environmental conditions for sockeye fry production from the standpoint that flooding did not occur.

Mean daily water temperatures (based on hourly recordings at Renton) are presented for August 1978 through June 1979 (Fig. 7). The thermal ranges during the 1978 spawning season were slightly lower than previous years and varied between 15.0 and 4.0°C. The lowest water temperature recorded was 1.0°C.

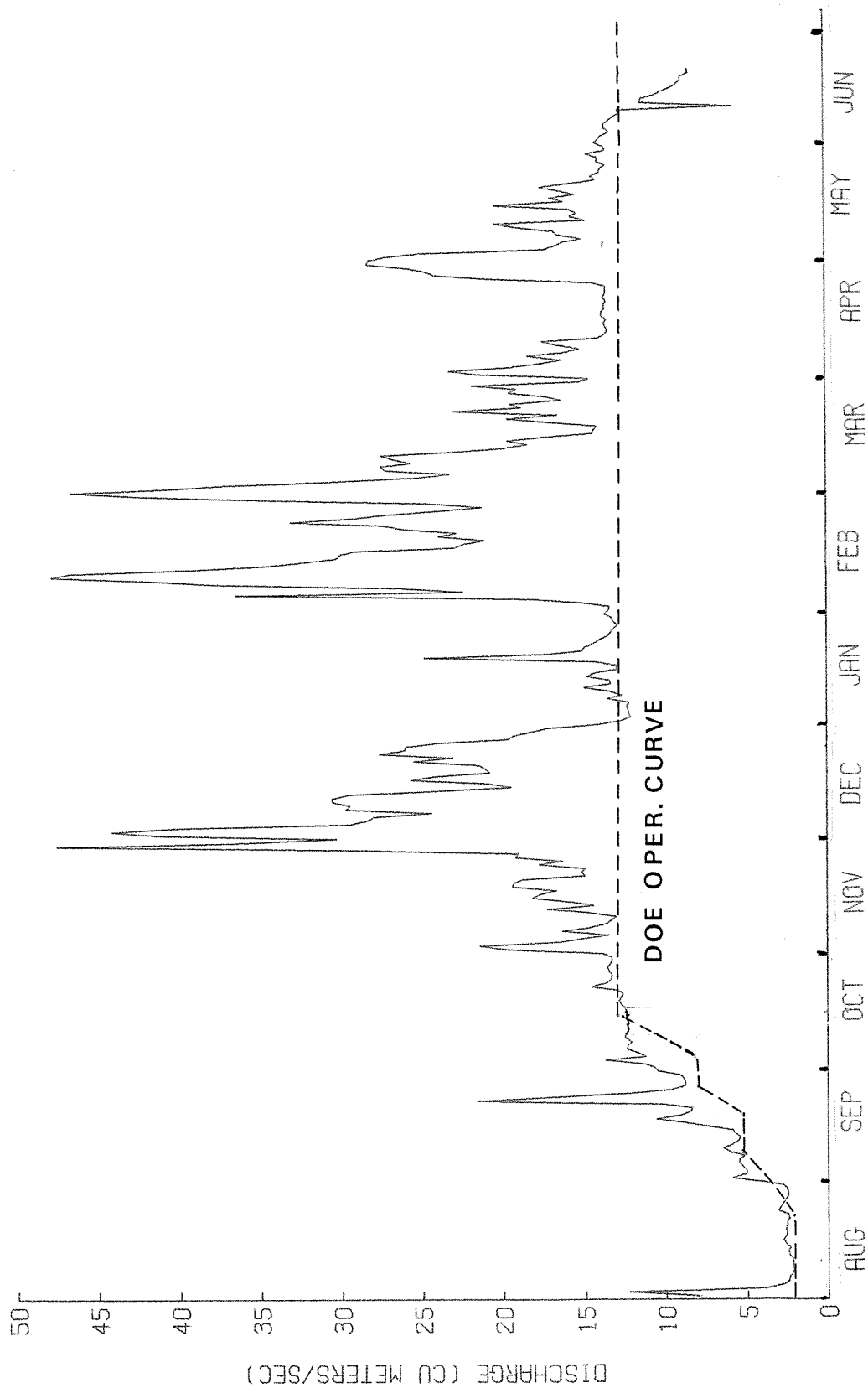


Fig. 6. Daily discharge at USGS Renton gauge from August 1978 through June 1979. (Source: U.S. Geological Survey)

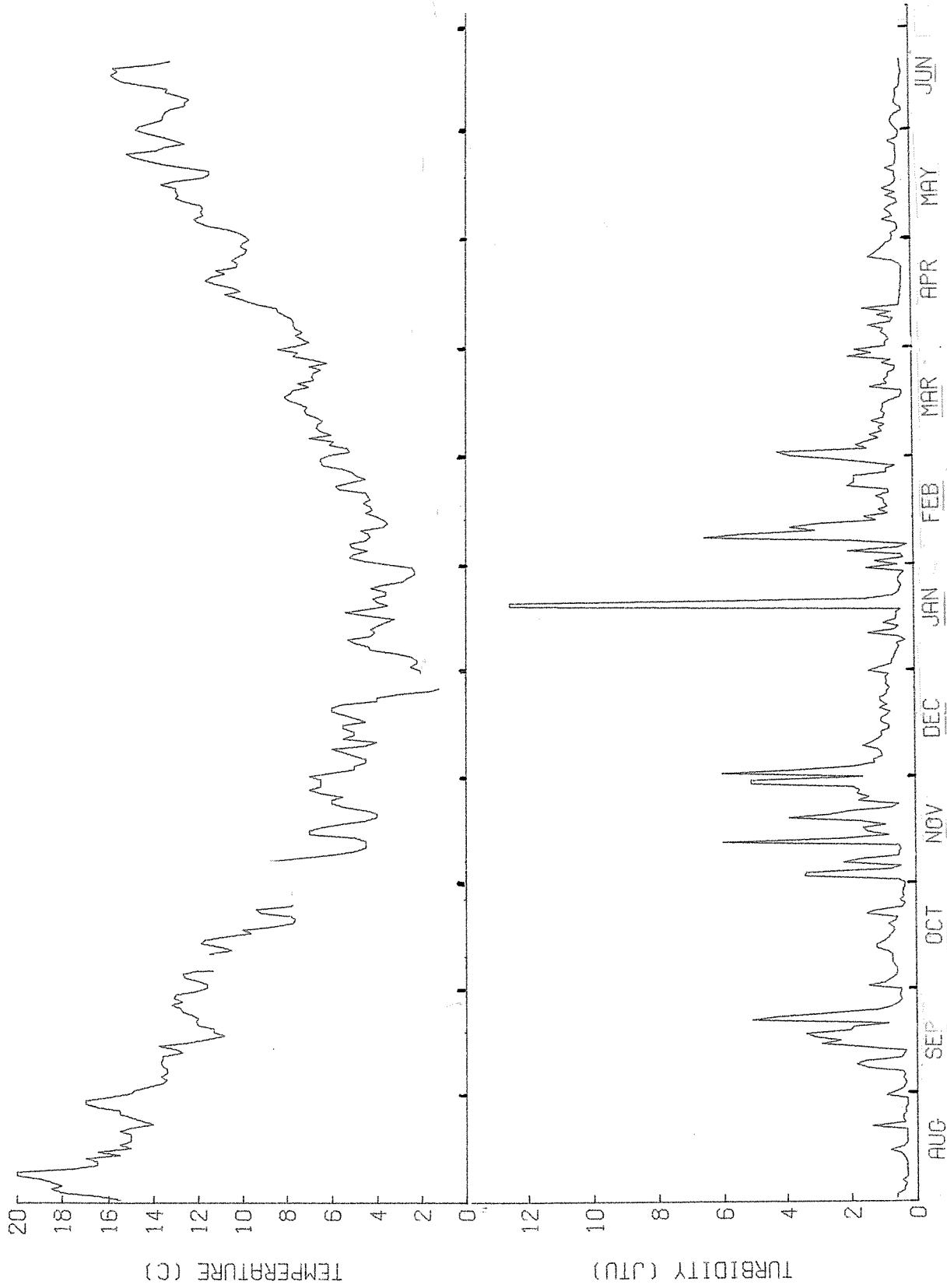


Fig. 7. Mean daily water temperatures at Renton and maximum daily turbidity at Landsburg from August 1978 through June 1979. (Sources: U.S. Geological Survey and Seattle Water Department)

The maximum daily turbidity readings at Landsburg for August 1978 through June 1979 were closely related to the discharge pattern (Fig. 7). Turbidity increased with discharge during late fall and winter.

6.2 Escapement

The total escapement of 277,801 sockeye to the Cedar River in 1978 was estimated by the WDF from tower counts (Fig. 8) of which about 15,000 salmon were taken for the enhancement program. Daily counts of migrating adult sockeye by WDF from a tower located at Rkm 8.5 are presented in Fig. 9. On September 1, prior to the initiation of tower monitoring, WDF conducted a float survey on the river from Landsburg to the tower site and recorded an early escapement of 13,150 sockeye salmon. The 1978 escapement was the fourth largest thus far estimated by the WDF. It was twice as large as in 1976 when similar environmental conditions were observed and fry production estimates were obtained.

The tower counts from September through November were characterized by a series of random peaks, although a general decline was observed throughout the spawning season (Fig. 9). About 50 percent of the escapement had entered the river by September 23 (Fig. 10) which was only one day later than the earliest escapement which occurred in 1972. Except for these two years, 50 percent of the escapement entered the river between October 6 and October 17. Early escapement during 1978 was not related to large increases in river discharge because only gradual increases were observed during late August and early September.

6.3 Fry Behavior and Emigration

The downstream migration of sockeye salmon fry was confined to the dark hours. Diurnal sampling in April indicated that less than 1 percent emigrated

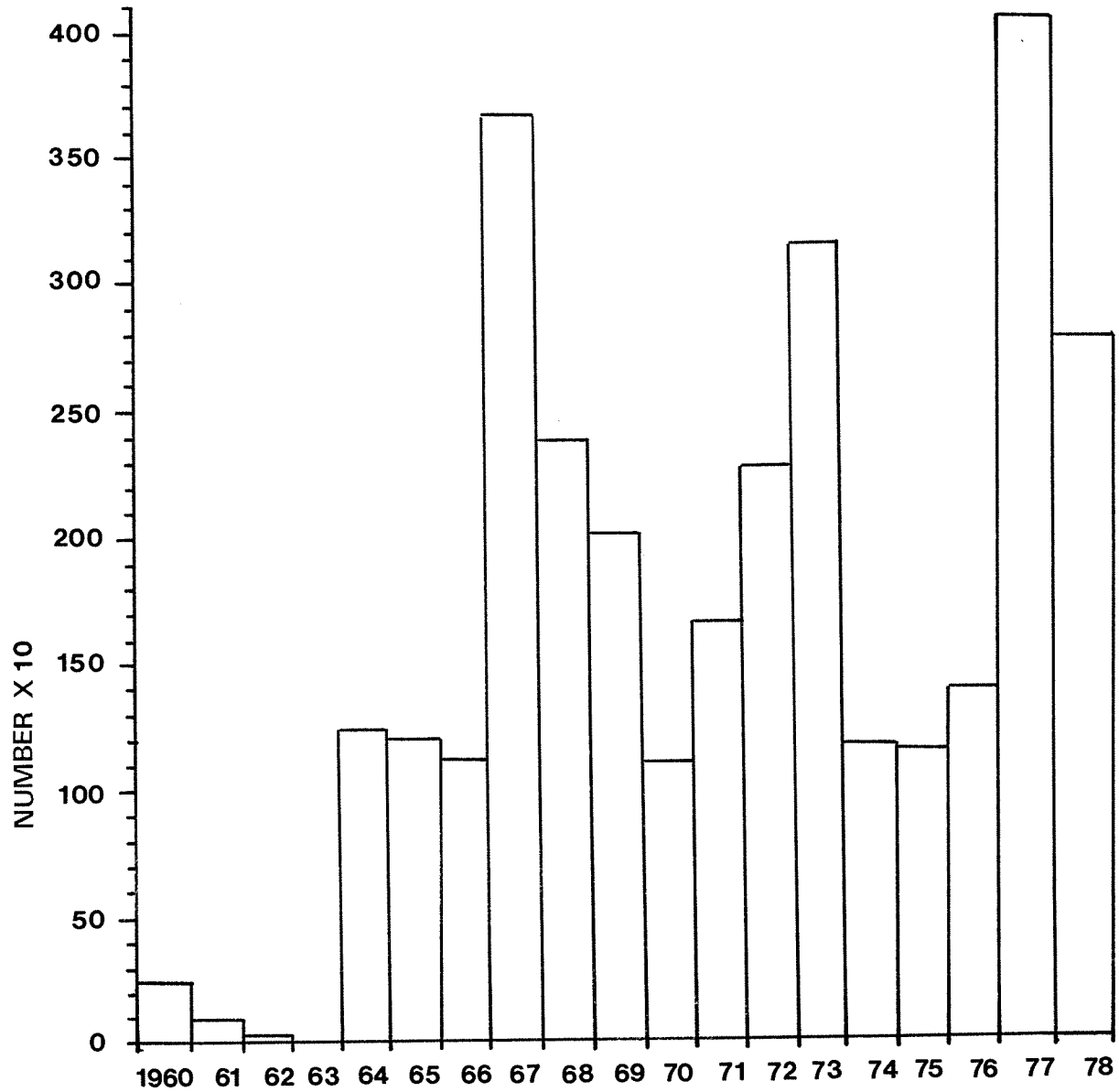


Fig. 8. Revised Cedar River sockeye salmon escapements 1960-1978 (WDF, unpublished).

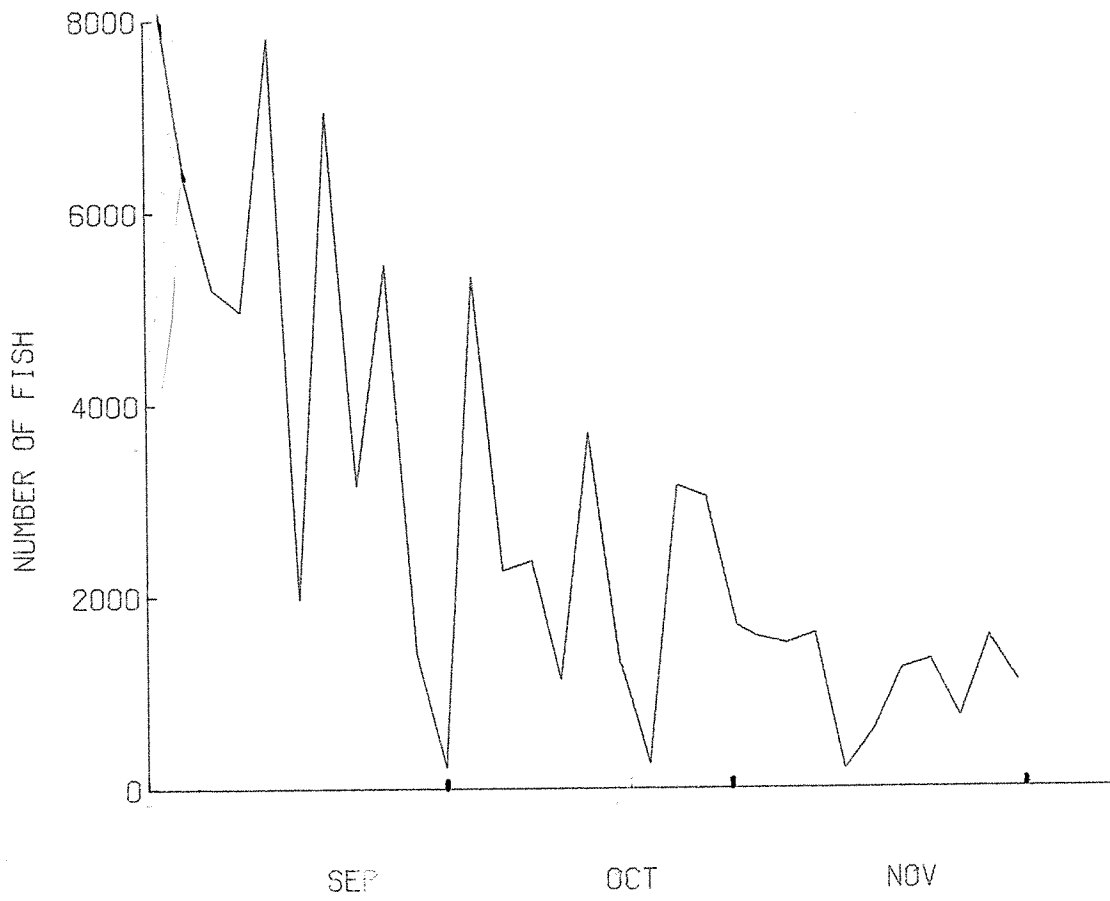


Fig. 9. Sockeye salmon tower counts, Cedar River, 1978.
(Source: WDF)

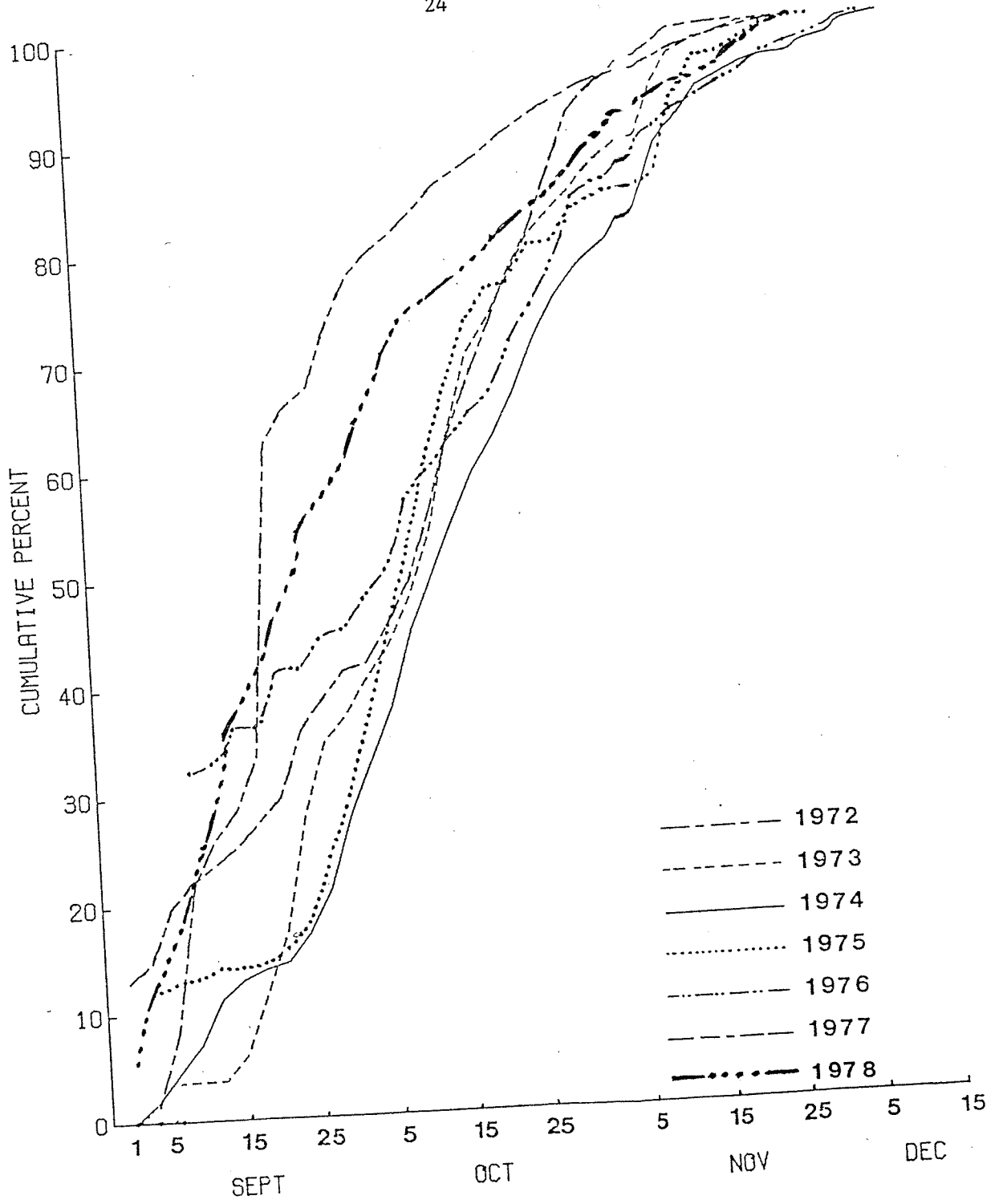


Fig. 10. Cumulative percentage of the tower counts by date for the Cedar River sockeye salmon escapement, 1972-1978. (Source: WDF)

during daylight hours. The downstream activity usually reached a peak from 2 to 5 hours after sunset (Fig. 11). A similar nightly behavior pattern was observed by Byrne (1971) under experimental conditions. Possible confounding due to site location was eliminated by restricting sampling to one site during diurnal testing. Another smaller peak was usually observed a few hours before sunrise. The timing of peak emigration varied nightly, indicating differences in river and weather conditions, and very likely the distance of migration. The nightly emigration period was shifted to later hours and became shorter as the photoperiod lengthened with the season.

If fry emerged from the spawning gravel shortly after sunset and drifted passively with the current, they could reach the lake before dawn. Hartman et al. (1962) observed active downstream movement by sockeye fry. The travel time of water from Landsburg to Renton has been estimated by the Seattle Water Department to be from 6 to 8 hours. The catch data indicated that all fry did not complete their downstream movement during the night of emergence but probably delayed under vegetation and rocks during daylight hours.

The captured fry exhibited photonegative behavior when exposed to light. During enumeration, fry formed a tight ball on the bottom of the bucket and tried to hide under debris. Fry released during daylight quickly disappeared under stones and vegetation. Small schools of fry were occasionally observed near the riverbank, but none could be seen by sunrise.

The horizontal distribution of sockeye fry across the river channel was generally related to the velocity and water depth (Fig. 12). Sites 2 and 3 had the highest catches, except during the first period (1/26-3/31) when Site 4 exceeded Site 2. Together, Sites 2 and 3 accounted for 61.2 percent of the total catch during the entire emigration period. Site 1 was most consistent throughout the season.

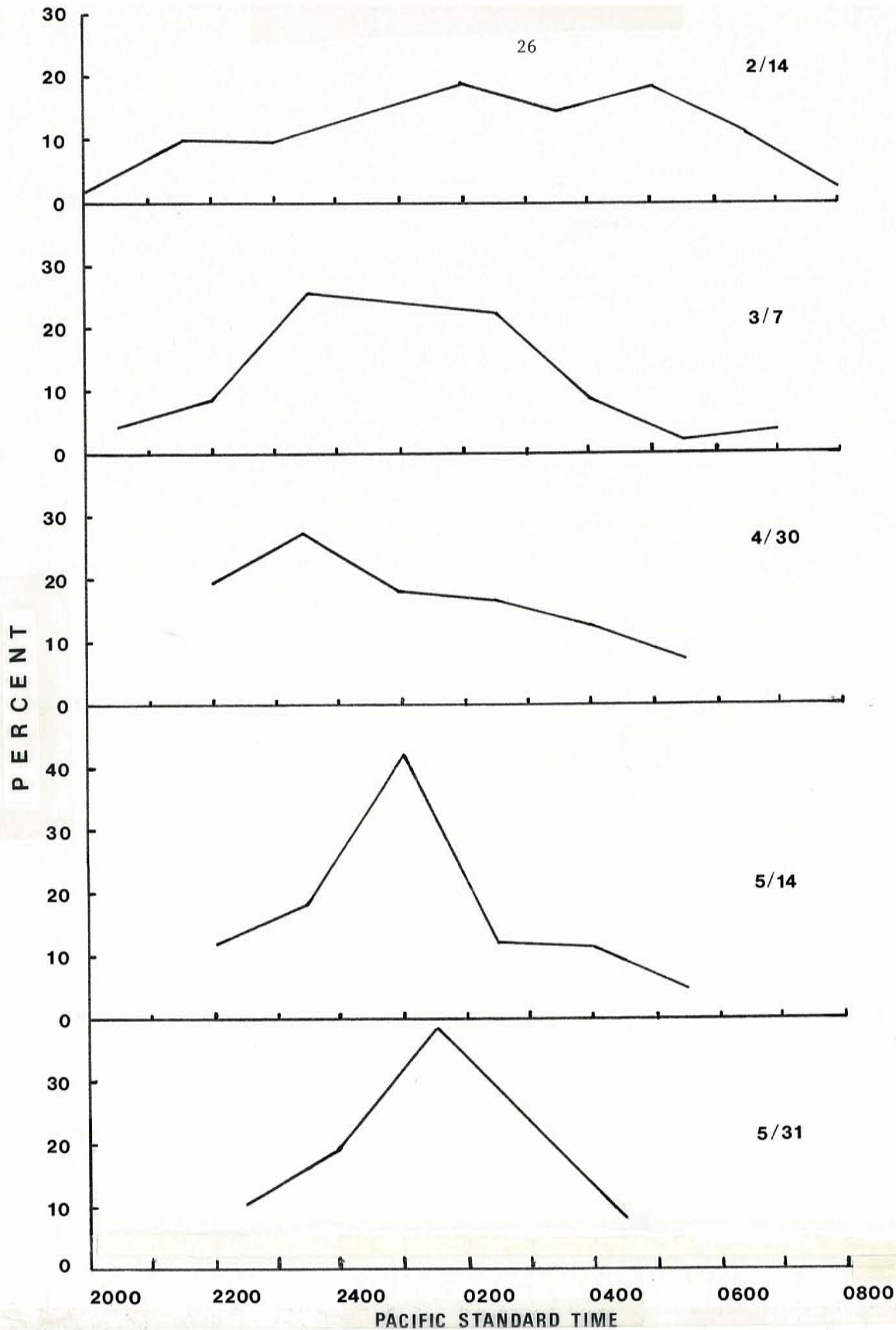


Fig. 11. Hourly distribution of nocturnal downstream movement of salmon during periods in 1979.

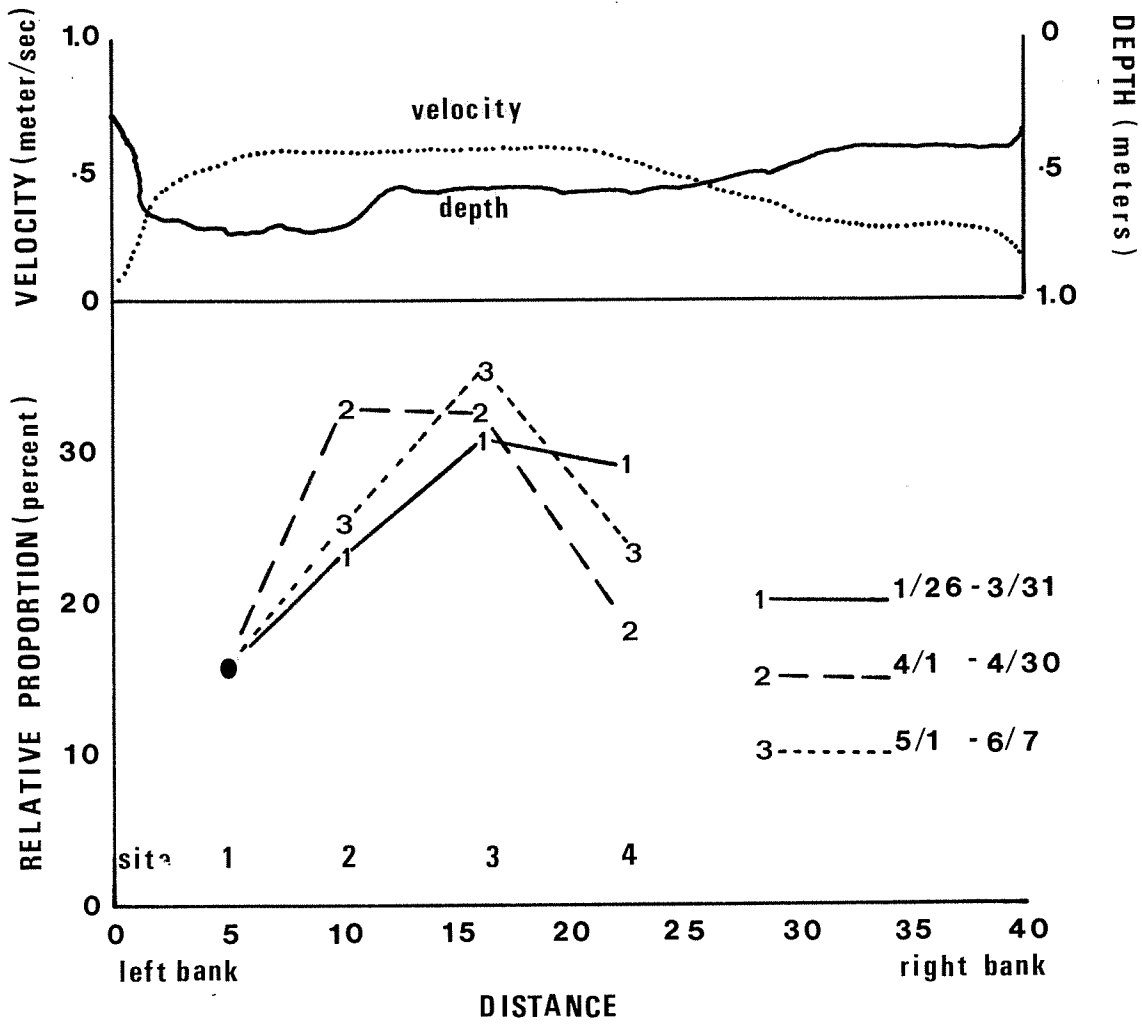


Fig. 12. Horizontal distribution of sockeye salmon fry by sample site during three periods of emigration with mean depth and velocity.

The estimated daily emigration exhibited a succession of peaks with two major periods of downstream movement: March 5 through April 2 and April 16 through May 14 (Fig. 13 and Appendix Table 1). The catches generally increased until March 5 when 370,000 fry were estimated. The daily estimates fluctuated between 200,000 and 620,000 fry for the next 4 weeks, and decreased for about 2 weeks. Another period of high emigration rate lasted for 1 month followed by a rapid decline on June 7, when the sampling was terminated.

Large day-to-day fluctuations in numbers of fry were caused by variations in discharge, water temperature, turbidity, light intensity, and the availability of fry. These factors were often combined which made it difficult to pinpoint any particular stimulus over a long period of time. Spearman correlation coefficients for nightly estimate, discharge, temperature and turbidity are given in Table 1. Temperature was a significant stimulus during the first two time periods (1/26-4/30). However, during the season downstream fry migrations occurred on nights with temperatures as low as 2.3°C and as high as 14.3°C. Turbidity was significant during the last time segment (5/1-6/7). Almost every major peak in discharge coincided with an increase in emigration; however, correlation was masked by the long time periods compared and the numerous other interacting factors.

Daily estimates were used to derive weekly emigration rates. Estimates were increased by 1.0 percent to account for the small daylight movement of fry. The weekly emigration pattern for 1979 is shown in Fig. 14. The main emigration period occurred from March 1 through mid-May with three major peaks evident. The observed and expected emigration pattern agreed quite closely in time with that calculated from time of spawning and TU information; however, a large number of fry expected in February and March failed to appear.

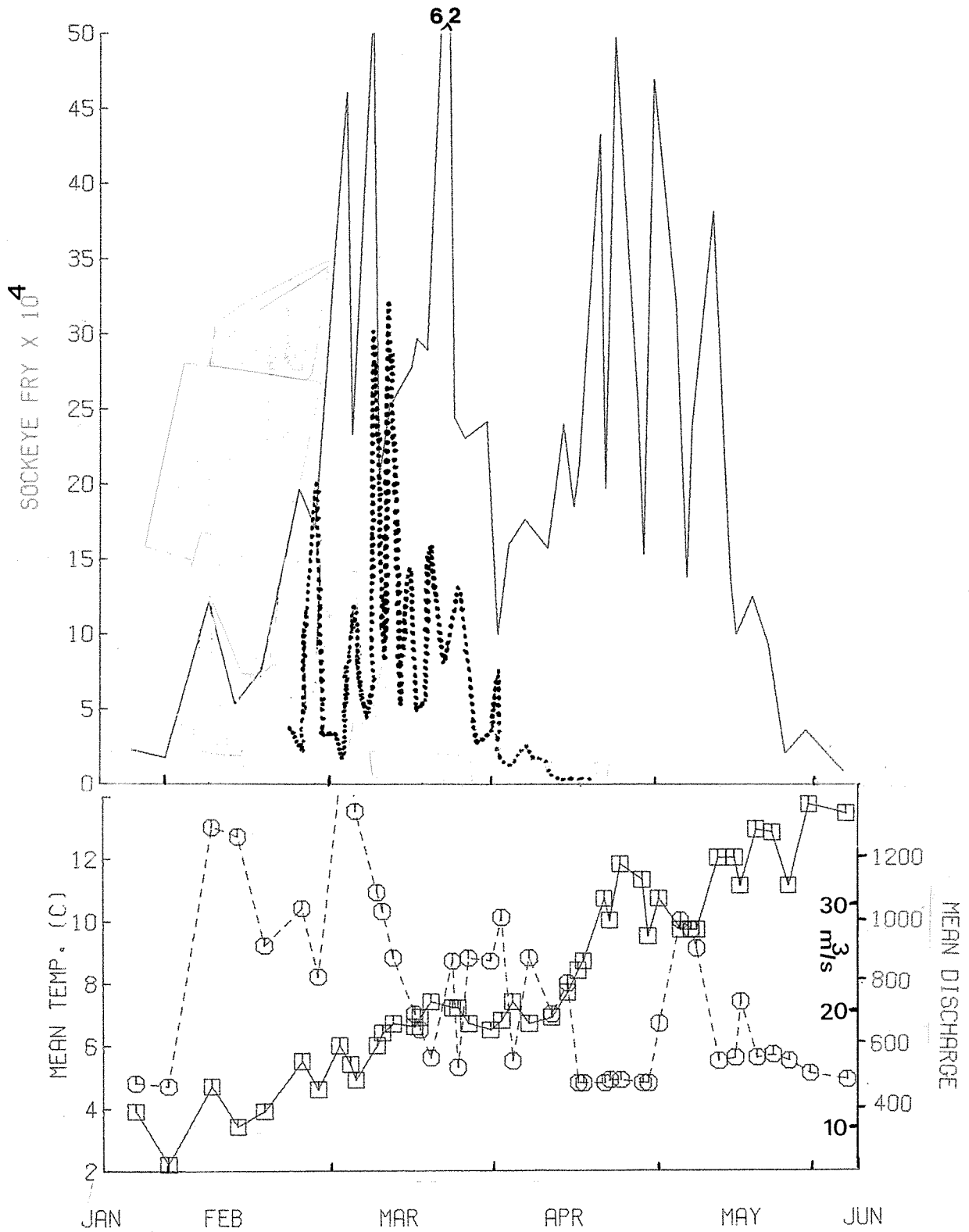


Fig. 13. Estimated daily emigration of sockeye salmon fry from the 1978 brood year, with number of fry released from the WDF index boxes (dashed line) and with mean nocturnal discharge and temperature.

Table 1. Relationship between the estimated number of sockeye fry and selected environmental factors (Spearman correlation coefficients) in 1979.

	Estimate	Discharge	1979	Temperature	Turbidity
			1/26 - 6/7		
Estimate	1.0000				
Discharge	.2291	1.0000			
Temperature	.0730	-.4125*		1.0000	
Turbidity	.1301	.6185**		-.3910*	1.0000
			1/26 - 3/31		
Estimate	1.0000				
Discharge	.2273	1.0000			
Temperature	.7285**	-.2154		1.0000	
Turbidity	-.1945	.6519*		-.5271*	1.0000
			4/1 - 4/30		
Estimate	1.0000				
Discharge	-.5028*	1.0000			
Temperature	.6503*	-.8023**		1.0000	
Turbidity	-.3859	.4043		-.3151	1.0000
			5/1 - 6/7		
Estimate	1.0000				
Discharge	.4325	1.0000			
Temperature	-.6205*	-.4486		1.0000	
Turbidity	.5667*	.3601		-.0990	1.0000

* Significant at the .05 level

** Significant at the .001 level

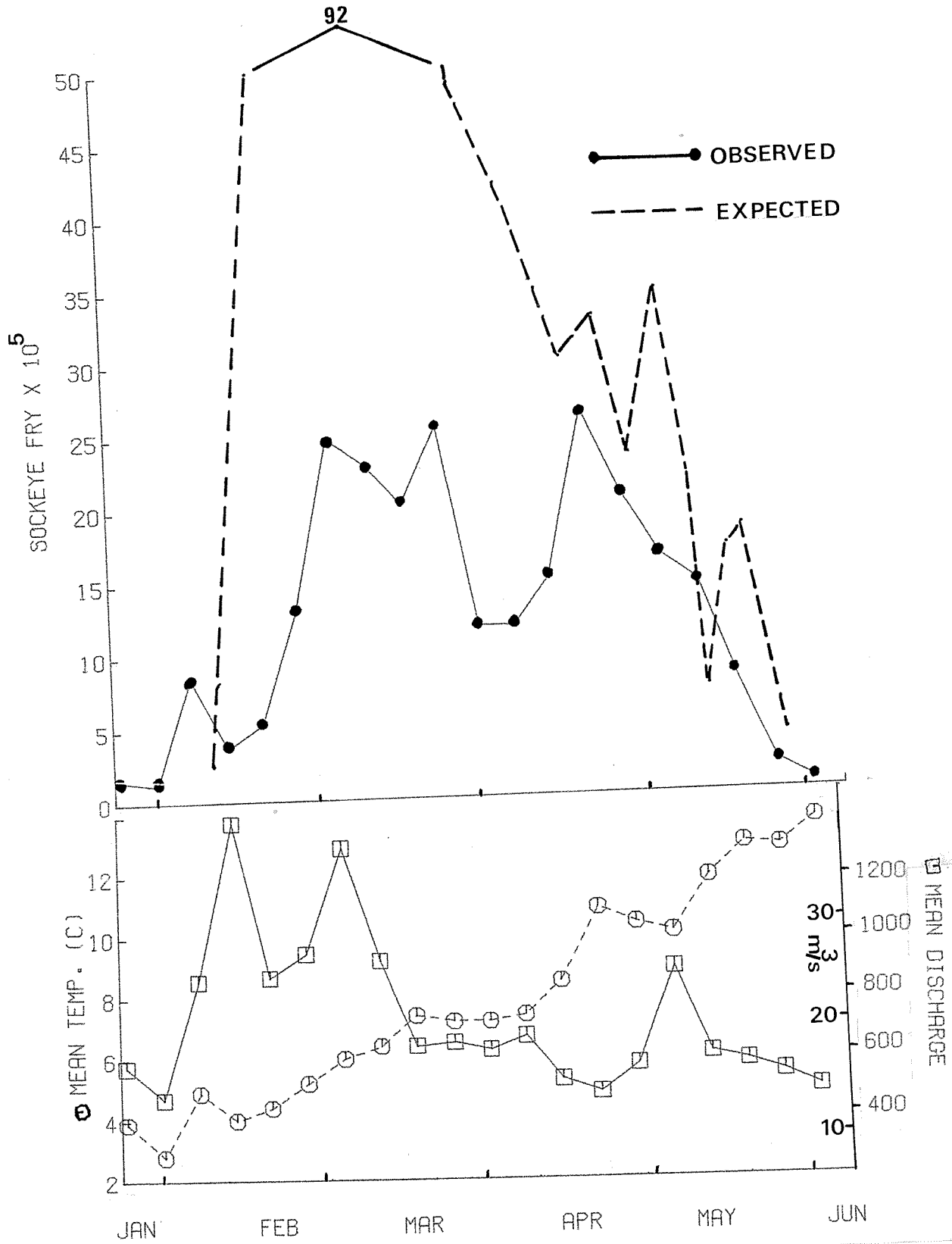


Fig. 14. Weekly observed and expected emigration of sockeye salmon fry from the 1978 brood year with mean temperature and discharge.

Cumulative and monthly fry outputs (percent) are plotted in Fig. 15. Fifty percent of the downstream movement was completed by March 25. The monthly fry outputs were as follows: January (0.8 percent), February (9.4 percent), March (39.9 percent), April (27.9 percent), May (21.4 percent) and June (0.6 percent). Over two-thirds emigrated in March and April.

A total of 44 sampling nights was distributed throughout the 4.5 month emigration period. The total estimate in 1979 was 25.5×10^6 ($\pm 2.6 \times 10^6$) fry.

6.4 Fry Survival

Based on the escapement estimates, sex ratio, and fecundity, the potential egg deposition for the 1978 brood year was calculated to be 5.64×10^8 eggs. Since 25.5×10^6 fry were estimated to have entered Lake Washington in 1979, a 4.5 percent egg-to-fry survival resulted.

The success of the various segments of the escapement was evaluated by dividing the season into three time periods: early (August and September), middle (October), and late (November and December) (Table 2). Almost half (46.0 percent) of the escapement spawned early and contributed 39.6 percent of the fry, the lowest survival (3.9 percent) of the three time periods. The middle and late portions of the escapement accounted for 32.1 and 21.9 percent of the run, contributing 35.3 and 25.1 percent of the fry produced. The survival was 5.0 and 5.2 percent, respectively for the middle and late run segments.

Foerster (1968) reported survival rates ranging from 1.8 to 19.3 percent (mean = 10.6 percent) for data collected from six river systems in British Columbia and the Soviet Union. Compared to previously published estimates, the survival of fry in the Cedar River in 1979 was low.

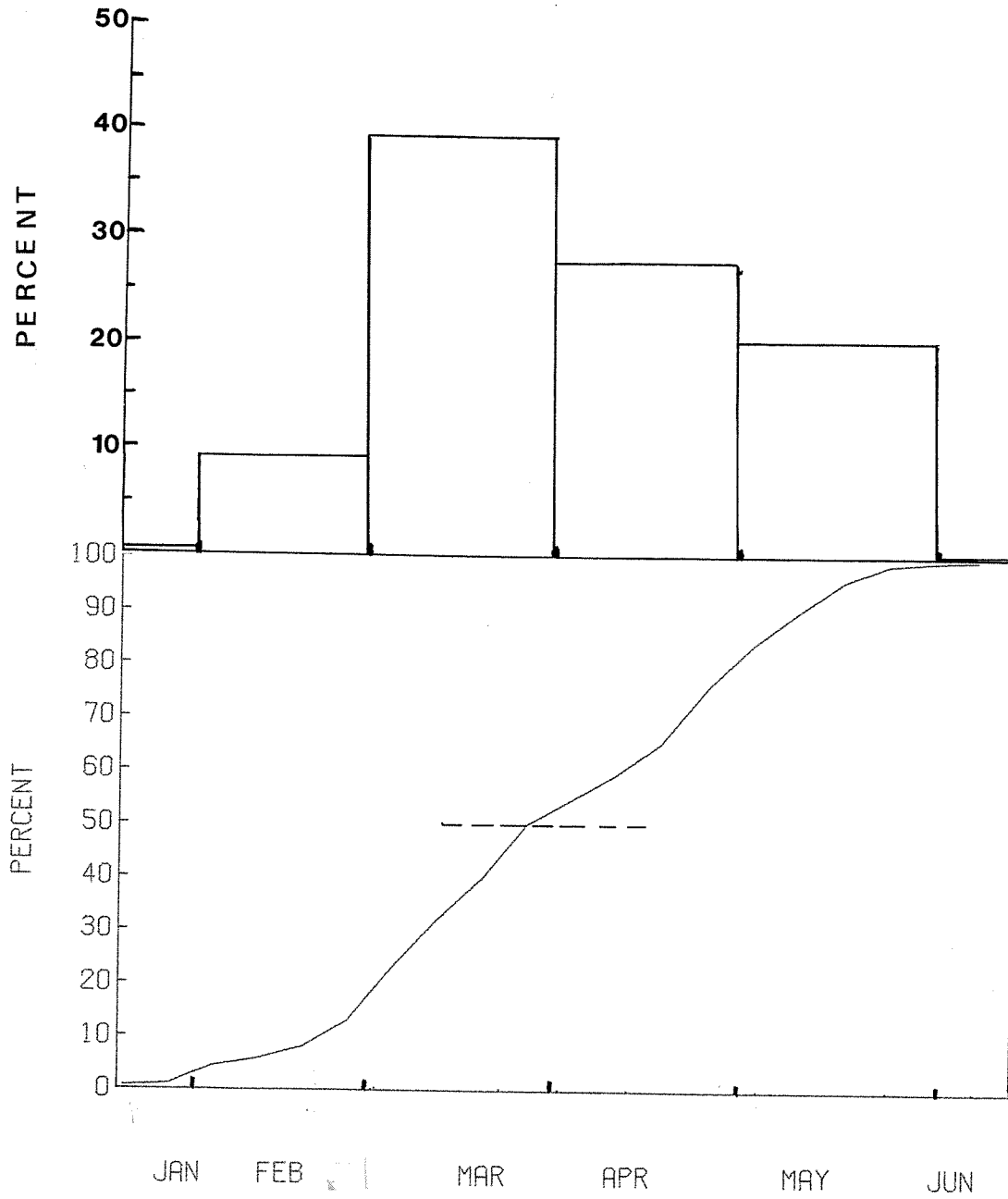


Fig. 15. Cumulative and monthly fry output from the 1978 brood year.

Table 2. Performance of the early, middle, and late portions of the 1978 brood year.

Dates Spawed	Escape-ment	%	Sex Ratio	Fecund-ity	Potential Egg Dep.	Expected Emergence	Days to Emergence	Fry Prod.	Survival %	Contribution
8/15 - 9/30	127,890	46.0	42:58	3500	259,617,000	1/15-3/24	175	10,110,000	3.9	39.6
10/1 - 10/31	89,104	32.1	42:58	3500	180,881,000	3/25-4/29	180	9,013,000	5.0	35.3
11/1 - 12/22	60,807	21.9	42:58	3500	123,438,000	4/30-5/29	158	6,392,000	5.2	25.1
	277,801	100.0			563,936,000		$\bar{x} = 171$	25,517,000	$\bar{x} = 4.5$	100.0

The pre-smolt to spawner (P/S) ratio for brood year 1978 was calculated for the Cedar River fry by equations of Bryant (1976) detailed by Stober et al. (1978a). This was necessary since acoustic smolt estimates in the lake have not yet been made for the 1978 brood year. The acoustic estimates also include smolts from sources other than the Cedar River as well as kokanee and it was necessary to calculate an independent estimate based only on the number of fry emigrating from the Cedar River. The equations used follow:

$$S = J e^{-mt}, \quad (7)$$

where

S = number of smolts,

J = number of juveniles in Lake Washington on July 1,

e = base of the natural logarithms,

m = the density-dependent monthly mortality rate calculated from equation (7),

t = number of months of lake residence,

$$m = (0.06245) + (0.00674)(J \times 10^{-6}). \quad (8)$$

In order to calculate S, it was first necessary to estimate the number of fish surviving to July 1 (J). This was done using an equation similar to (7) which accounted for changing density resulting from monthly recruitment of emigrant fry. The number of fish surviving on month $i + 1$ was calculated by the following equation:

$$N_{(i+1)} = (E_i + n_i)e^{-mt}, \quad (9)$$

where

- $N_{(i+1)}$ = number of fish surviving on month $i + 1$,
- E_i = number of fish emigrating into Lake Washington on month $i + 1$,
- n_i = number of fish surviving on month i which had previously emigrated,
- m = mortality rate (see equation [8]),
- t = number of months in lake prior to July 1.

In 1979, an estimated 25.5×10^6 Cedar River fry entered Lake Washington, with an estimated 14.2×10^6 fry surviving to July 1. An estimated 2.1×10^6 smolts will be produced, representing a 7.7 P/S ratio. This is only about one-third of the P/S ratio (20.1) for the 1976 brood year which experienced similar discharge conditions. Miller (1976) estimated the maximum P/S ratio to be 21.0. The sharp decline in the 1979 P/S ratio under a discharge regime similar to 1976-1977 suggests other factors are controlling survival.

6.5 Fry Quality

The 1979 length frequency distribution of sockeye salmon fry is given in Fig. 16. Over 94 percent of the fry ranged from 25 to 29 mm in length. The mean lengths fluctuated between 26.0 and 27.9 mm, with no strong seasonal trend (Table 3). The weight generally decreased with the season until late May when larger fry were encountered in the samples (Table 3). The weights fluctuated between .1470 and .1740 g during the main emigration period.

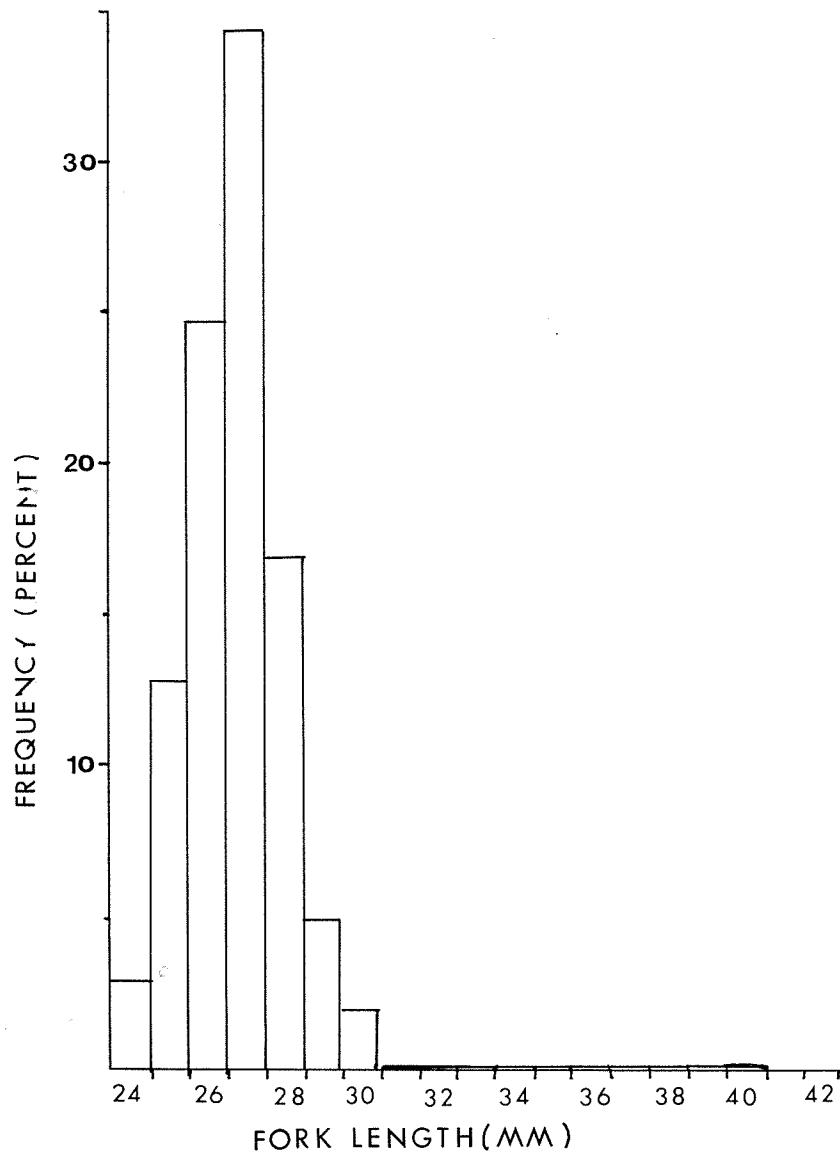


Fig. 16. Length frequency distribution of sockeye salmon fry in 1979.

Table 3. Mean length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for sockeye salmon fry sampled by fykenetting in 1979.

Week	N	Length (mm)	Weight (g)	Condition factor	Percent of complete fusion
1/21	50	27.1	.1740	.87	37.0
1/28	50	27.0	.1698	.86	43.0
2/4	50	27.5	.1736	.83	27.0
2/11	50	27.0	.1664	.85	33.0
2/18	50	26.7	.1604	.84	44.0
2/25	50	26.9	.1570	.81	59.0
3/4	50	27.1	.1598	.80	53.0
3/11	50	27.2	.1566	.78	73.0
3/18	50	27.4	.1536	.75	81.0
3/25	50	26.6	.1474	.78	74.0
4/1	50	26.8	.1526	.79	72.0
4/8	50	26.6	.1540	.82	58.0
4/15	50	26.6	.1492	.79	53.0
4/22	50	26.3	.1490	.82	60.0
4/29	50	26.1	.1470	.83	43.0
5/6	50	26.0	.1530	.87	51.0
5/13	50	26.0	.1470	.84	51.0
5/20	50	26.3	.1550	.85	54.0
5/27	50	26.9	.1678	.86	73.0
6/3	50	27.9	.1934	.89	77.0
\bar{X}	50	26.8	.1593	.92	55.8

Condition factors ranged from 0.75 to 0.89 (Table 3). They tended to decrease until mid-March, followed by a general increase.

The degree of reabsorption of the yolk reserves was recorded to determine seasonal changes and relationship with environmental factors. The percent of complete fusion was relatively low throughout the sampling season, ranging from 27.0 to 81.0 percent (Table 3). Fry at the mid-point of the emigration period had the highest percentage, followed by fry during the last 2 weeks of the season. In general, a high condition factor results with incomplete fusion due to the greater amount of yolk present. The condition factor was probably somewhat biased for fry captured from late May until the end of the season, because it was evident that some of these fish were larger (> 30 mm) and probably rearing in the river. From January until late May the fry sizes indicated that newly emergent fry were sampled during emigration past the sampling site.

Size of the emerging fry is probably an important factor in determining their survival. Predator selectivity studies by Bams (1967) and Beall (1972) indicated a direct correlation between fry vulnerability and length and stage of development. A general decrease in weight was observed until the time when about 50 percent of the emigration had occurred. This coincided with the lowest condition factor and the highest proportion of fry with complete fusion of the mid-ventral wall. The proportion of "buttoned-up" fry was unusually low throughout the emigration period. Flood discharges, which could have scoured alevins from the spawning beds, were not recorded during the 1978-79 incubation period. The condition factor is a good general measure of well-being; however, it can produce artificially high results when a high percentage of fry have yolk sacs remaining. These fish are emerging prematurely and probably will not experience a high survival.

6.6 Artificial Enhancement

The WDF has been developing incubation facilities for sockeye salmon at Landsburg since 1975. The fry production has increased each year and the total WDF estimate was 9.5×10^6 in 1979. The WDF daily and cumulative fry counts from the index incubation boxes are given in Table 4. Fry emerged from the incubation boxes from February 1 through mid-April (Fig. 13). It is evident that emergence from the boxes occurred largely during the early portion of the natural emergence period. Continuous temperature data were not available for the incubation facilities to compare the development rates of natural and artificial fry. About 80 percent of the eggs were taken from October spawners (middle portion of spawning run) but 87 percent of the fry emerged before March 24 (early portion of emergence). This may have been due to warmer water temperatures in the incubation boxes. This placed most of the artificial fry contribution in the early emergence period which had the lowest survival rate of 3.9 percent.

The WDF, aided by the National Fishery Research Center, Seattle, identified a high incidence of infectious hematopoietic necrosis (IHN), a viral disease, in the artificially produced fry. IHN virus was isolated in all twelve sample lots taken from the incubation boxes. Fry captured at the mouth of the Cedar River were also tested for disease. Samples were taken on April 26, May 10 and May 24. In April, 25 percent of the individually tested fry were affected; however, the virus was not found in the May samples. All fry captured at the river mouth were from natural production since emigration from the incubation boxes had ceased by mid-April (Table 4). Williams and Amend (1976) reported the first confirmed epizootic of IHN under natural conditions for sockeye salmon in Chilko Lake, British Columbia. The egg-to-fry survival of 3.8

Table 4. Number of sockeye salmon fry released from the index gravel boxes in 1979. (WDF data).

Date	Daily	Cumulative	Date	Daily	Cumulative
2/22	42709	42709	3/21		
23			22	139390	2331905
24	23850	66559	23	91425	2423330
25			24	69695	2493025
26	213687	280246	25	47700	2540725
27	36370	316616	26	25175	2565900
28	37088	353704	27	30475	2596375
3/ 1	39750	393454	28	36835	2633210
2	19610	413064	29	86233	2719443
3	60364	473428	30	19610	2739053
4			31	16430	2755483
5	122046	595474	4/ 1	11395	2766878
6	46375	641849	2	14045	2780923
7			3	16695	2797618
8	74730	716579	4	23320	2820938
9	316779	1033358	5	22790	2843728
10	40545	1073903	6		
11			7	5565	2849293
12	335988	1409891	8		
13	51145	1461036	9	7685	2856978
14	106962	1567998	10		
15	106000	1673998	11		
16	156945	1830943	12	3710	2860688
17	56180	1887193	13		
18	61745	1948868	14		
19	161232	2110100	15		
20	82415	2192515	16	795	2861483

percent was the lowest ever recorded at Chilko Lake over a 25-year period. This disease may have caused additional mortality of sockeye fry in the Cedar River in 1979.

The quality of the artificial and wild fry during the same period is compared in Table 5. Both types of fry were measured by the junior author in the same laboratory. Fry emerging from the incubation boxes were consistently shorter and had more yolk visible than the ones captured at the river mouth. Weights and condition factors were higher, a phenomenon often observed in premature fry; however, chances for survival are generally reduced for fry with large yolk sacs (Bams, 1967).

Since the artificially produced fry could not be distinguished from the naturally produced fry in the catch at the river mouth, mortality could not be estimated. Such estimates are needed in order to determine the effectiveness of the enhancement program.

6.7 Sampling Mortality

Mortality due to sampling with the fyke net and associated handling was determined on nine occasions in 1979. No attempt was made to separate different causes of mortality. Mortality varied from a low of 1.5 to 9.2 percent with a mean of 4.1 percent (Table 6). A total of 3.6×10^5 fry were captured in 1979 with an estimated 1.5×10^4 fry killed during the entire sampling period. This represents a very small portion of the total estimated 25.5 million fry.

6.8 Incidental Species

The actual catch of a number of other species of fish captured during this study is given in Table 7. Total estimates were not made for these species.

Table 5. Mean length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for sockeye salmon fry from the WDF incubation and the fyke net catches in 1979.

Date	N		Length (mm)		Weight (g)		Condition factor		Percent of complete fusion	
	WDF	F.N.	WDF	F.N.	WDF	F.N.	WDF	F.N.	WDF	F.N.
3/4	50	50	26.2	27.1	.1706	.1598	.95	.80	46.0	53.0
3/11	50	50	26.0	27.2	.1752	.1566	1.00	.78	28.0	73.0
3/18	50	50	26.8	27.4	.1538	.1536	.80	.75	74.0	81.0
4/1	50	50	26.3	26.8	.1470	.1526	.81	.79	62.0	72.0
\bar{X} =	50	50	26.3	27.1	.1617	.1557	.89	.78	52.5	69.8

Table 6. Number of fry killed during the fyke net sampling in 1979.

Date	Number of fry killed	Total	Percent
2/19	11	119	9.2
3/5	8	130	6.2
3/19	9	157	5.7
4/2	3	107	2.8
4/16	5	147	3.4
4/23	3	119	2.5
5/3	6	146	4.1
5/17	2	123	1.6
5/31	2	131	1.5
Mean			4.1

Table 7. Weekly catch of incidental species in 1979.

Date	Fry			Fingerling						
	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Longfin smelt	Threespine stickleback	Lamprey	Cottids
1/21		13								
1/28		30		1	1		1			4
2/ 4		39								15
2/11		16		1					2	10
2/18		17		1					1	7
2/25		61		2					1	5
3/ 4		269		6		1				11
3/11		375		2			2			12
3/18		418		3			2		3	10
3/25		1019		3		1	2		1	7
4/ 1		747		1			1		1	5
4/ 8	1	371			1		1			
4/15		144		4			1		1	
4/22		139		2	2	1			2	1
4/29	1	295		10			1			2
5/ 6	21	277		35						2
5/13		140	3	33	1	5		2	1	3
5/20	1	57	10	5	3					4
5/27	15	39	4	11			1	1		4
6/ 3		4	7							4
										1
Total	40	4470	24	120	8	8	8	3	14	107

Chinook salmon fry (*Oncorhynchus tshawytscha*) were the most abundant incidental species in 1979. Cottids (*Cottus* sp.) and juvenile coho salmon (*O. kisutch*) were frequently seen in fyke net catches. Steelhead trout (*Salmo gairdneri*), longfin smelt (*Spirinchus thaleichthys*), threespine stickleback (*Gasterosteus aculeatus*), and lampreys (*Lampetra* sp.) were captured sporadically.

7.0 SUMMARY AND CONCLUSIONS

The estimated escapement of 277,801 sockeye salmon in the fall of 1978 was the fourth largest ever and the second earliest recorded since 1972 in the Cedar River. The discharge regime during the spawning season generally exceeded the DOE operating curve and may have contributed to an increase in redd superimposition. Sockeye egg incubation was not subjected to flood discharges greater than $47.6 \text{ m}^3/\text{s}$ during the 1978-79 period. Maximum instantaneous discharge less than $50 \text{ m}^3/\text{s}$ has been found to have little effect on sockeye survival according to analysis of pre-smolt to spawner ratios in years differing in flood discharge during incubation.

The fry emigration was monitored by fyke net sampling at the mouth of the Cedar River. A total of 44 sampling nights was distributed over a 4.5 month emigration period. The total estimate of downstream migrants was 25.5×10^6 sockeye fry. This included the survivors from 9.5×10^6 fry artificially produced in the WDF incubation facility at Landsburg. Egg-to-fry survival for the entire run was 4.5 percent. Early (August-September), middle (October) and late (November-December) segments of the escapement resulted in corresponding fry survival rates of 3.9, 5.0 and 5.2 percent, respectively. Survival of the early segment of the run has been lowest during previous years and although

87 percent of the artificially produced fry emerged during the early segment, survival remained the lowest. Calculation of the 1979 pre-smolt to spawner ratio showed a projected decline to 7.7, based on an estimate of 2.1×10^6 smolts, the second lowest since 1967.

The incidence of infectious hematopoietic necrosis (IHN), a viral disease, was suspected of reducing the survival of the artificially-produced fry in 1979. This disease was also detected in the natural fry in late April but not in May. This is the first year that IHN is known to have been isolated in the Cedar River fry. Infestation may increase when fry are artificially incubated due to increased density and dense spawning populations may increase the passage of the disease among the natural population. Since the artificially-produced fry could not be distinguished from naturally-produced fry in the catch at the river mouth, differential mortality could not be estimated. Such estimates are needed in order to determine the effectiveness of the enhancement program.

Table 8 presents the comparisons between three brood years (1975, 1976 and 1978) on which fry production estimates have been made. The 1975 brood year was impacted by the most extreme flood thus far recorded for the river and a very low fry estimate resulted, representing only 0.8 percent survival from egg-to-fry. The 1975 flood is estimated to have caused a 38 percent reduction in the total maximum instantaneous spawned area between 1975 and 1976 with roughly comparable spawning populations (Stober et al. 1977b). This loss of spawning gravel appears to be even more extreme when compared with the area spawned in 1973 of $143,995 \text{ m}^2$ when 313,000 spawners ascended the river. The loss of spawning habitat was apparently sustained through 1977 since the total instantaneous area spawned was estimated to have remained at about $61,000 \text{ m}^2$ even with the largest-

Table 8. Comparison of various parameters during three years of fry enumeration.

	1975-76	1976-77	1978-79
Escapement	114,100	138,949	277,801
Peak discharge (m ³ /s)	249.2	34.6	47.6
Time to 50% escapement	10/8	10/6	9/23
Total instantaneous spawned area (m ²)	9.3x10 ⁴	5.8x10 ⁴	N.A.
Fry estimate (total)	1.8x10 ⁶	22.8x10 ⁶	25.5x10 ⁶
Artificial enhancement	0.04x10 ⁶	0.8x10 ⁶	9.6x10 ⁶
Time of 50% of emigration	4/21	3/21	3/23
Egg-to-fry survival	0.8	8.1	4.5
P/S ratio	5.8	20.1	7.7
Fry quality (2/4-5/7)			
Length	27.0	27.3	26.8
Weight	.1412	.1623	.1557
Condition factor	.72	.80	.81
Percent of complete fusion	83.8	90.1	55.8
Disease	unknown	unknown	IHN

ever escapement of 410,000 spawners. It is probable that the habitat loss following the severe 1975 flood has been sustained through the 1978 brood year and will remain so until sufficient time has passed that the spawning gravel is replaced naturally. This process can be expected to be slowed because of the presence of two dams on the river which restrict the recruitment of gravel from upstream areas in the basin.

The environmental conditions experienced by brood years 1976 and 1978 were comparable; however, the escapement doubled in the second year. Fry production was about equal for both years; however, survival of an unknown portion of 9.5×10^6 fry was included from the enhancement project. From 1976 to 1978 the egg-to-fry survival declined from 8.1 to 4.5 percent and the pre-smolt to spawner ratio is projected to decline substantially from 20.1 to 7.7. The percent of complete fusion of emergent fry declined in 1979 from previous years and the incidence of infectious disease (IHN) became a suspected mortality factor in 1978-79.

Based on the present information we believe that the drop in survival of the 1978 brood year fry is probably the result of density-dependent factors (redd superimposition) resulting from the increased 1978 escapement level in a spawning habitat previously reduced by flooding. Disease was apparently a contributing factor which may be related to crowding under natural and artificial conditions. Further monitoring is needed to confirm these conclusions and to evaluate the effectiveness of the enhancement program. Additional monitoring to assess the total instantaneous area spawned in the river would provide an assessment of the rate of recovery of the natural spawning habitat in the river channel. A reduction in the escapement may be needed to achieve greater efficiency in the egg-to-fry survival rate.

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Appendix Table 1. Daily sockeye fry estimates, mean temperatures, mean discharge (Q) in the Cedar River, and turbidity, 1979.

Date	Estimate	Temperature	Q	Turbidity
1/26	22653	3.9	480	2
2/1	17534	2.2	470	15
2/9	121307	4.7	1300	25
2/14	53119	3.4	1270	18
2/19	76080	3.9	920	10
2/26	196795	5.5	1040	22
3/1	170965	4.6	820	15
3/5	369429	6.0	1420	20
3/7	461150	5.4	1570	15
3/8	233036	4.9	1350	13
3/12	523854	6.0	1090	10
3/13	205192	6.4	1030	11
3/15	252406	6.7	880	8
3/19	277752	6.6	700	6
3/20	297167	6.9	650	6
3/22	289276	7.4	560	7
3/26	615963	7.2	870	8
3/27	244300	7.2	530	5
3/29	230631	6.7	880	4
4/2	241896	6.5	870	5
4/4	99784	6.8	1010	9
4/6	160251	7.4	550	7
4/9	176799	6.7	880	9
4/13	157181	6.9	700	8
4/16	240267	7.7	800	9
4/18	184881	8.4	480	8
4/19	213386	8.7	480	3
4/23	432949	10.7	480	4
4/24	196915	10.0	490	5
4/26	497421	11.8	490	4
4/30	253867	11.3	480	10
5/1	153103	9.5	480	5
5/3	469557	10.7	670	9
5/7	320572	9.7	1000	9
5/9	137876	9.7	970	3
5/10	238825	9.7	910	9
5/14	381843	12.0	550	10
5/17	137153	12.0	560	6
5/18	100045	11.1	740	8
5/21	125168	12.9	560	7
5/24	92716	12.8	570	6
5/27	20681	11.1	550	6
5/31	36042	13.7	510	5
6/7	9050	13.4	490	6

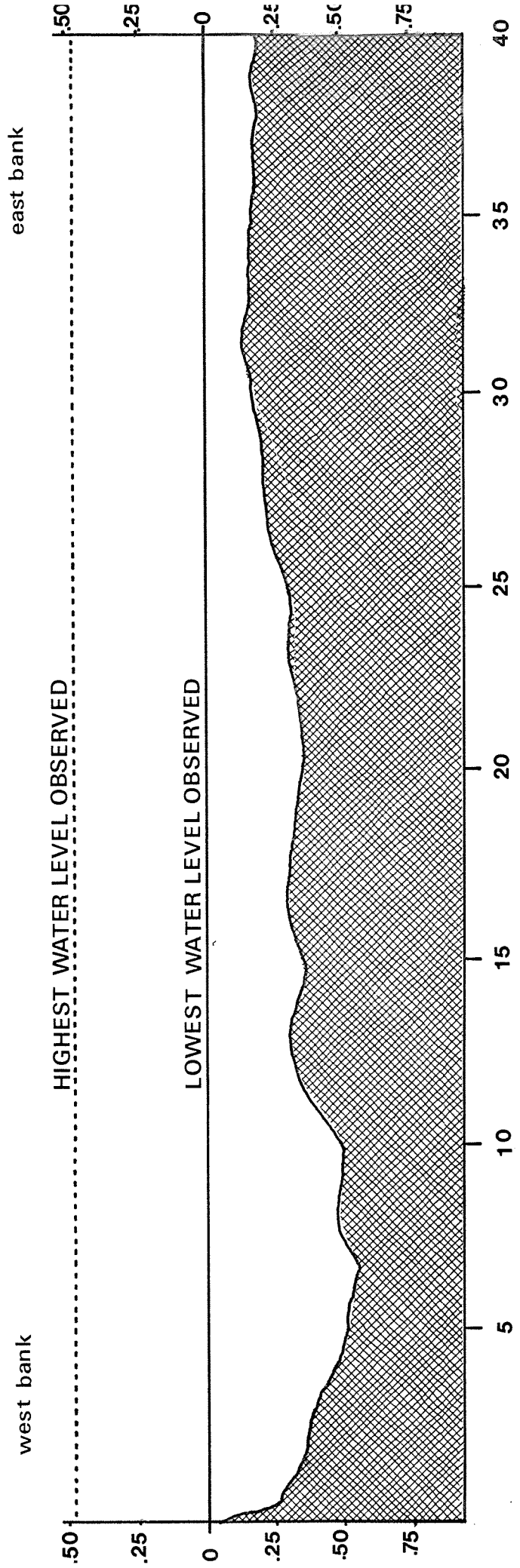


Fig. 2. Cross-section of the Cedar River at the fyke net sampling site.